Developing the potential of fish processing byproducts takes guts

Dr. Peter Bechtel
USDA/Agricultural Research Service

Pete Nicklason
University of Idaho

Dr. Michael Rust
NOAA Northwest Fisheries Science Center

and Dr. Scott Smiley
University of Alaska
Fishery Industry Technology Center

If you ask a pork producer about how much of his product is actually used by society, he is likely to reply, “We use everything but the squeal”. In fact, much of agriculture has long made good use of the various parts of animals that humans don’t eat. Much of these so called ‘byproducts’ or ‘coproducts’ are usually processed into feed for pets and livestock. While the recovery and repurposing of all parts of terrestrial animals is quite efficient, recovery of fish parts is just starting to improve.

If you buy a nice one pound fillet at your local fishmonger, it is likely that about one pound of other potentially useful stuff has also been generated in cutting that fillet. Various terms such as ‘fish trimmings’, ‘fish wastes’, ‘fisheries byproducts’, ‘fisheries coproducts’, ‘fish scraps’, and even ‘fish offal’ (pronounced “awful”) are used to describe various components of the left over heads, guts, fins, bones, and skin that are left over after cutting two fillets from a whole intact fish.

Nowhere is the potential to effectively capture this valuable material greater than in the State of Alaska. The Alaskan seafood industry harvests more than half of the total U.S. commercial fish catch each year and processing this harvest into food for people leaves over 1.1 million tons of fish processing waste. Experts have estimated that a quarter of this waste may be discarded and it’s potential value lost.

The challenge in Alaska and elsewhere, is that much of this fish processing waste is created seasonally in remote areas with poor infrastructure. Additionally, given the biology of the fish, they are often available in huge amounts but for only a very short season. Because fish spoil so quickly and because a huge volume of fish processing waste is produced in such a short period of time, it requires big expensive equipment and a good deal of energy to process it all before it spoils. After the season, there is nothing to do with that expensive equipment until the next harvest occurs. For some fisheries this might mean a six week-long season followed by the rest of the year off.

Aside from the huge processing operations along the shore of the Bering Sea, small processors specializing in remote and seasonal fisheries, such as salmon, rarely generate sufficient volumes of fish processing waste to justify investment in large scale equipment. The intermittent nature of the fishery, and the remote seasonal nature of the locations the fish are processed, mean that traditional approaches such as those used by the year round pork and chicken industries are not cost-effective when it comes to fish, so waste material ends up back in the sea.

Driven by the sheer potential for economic and environmental gains, state and federal researchers are developing techniques that will help industry and local communities tap into the value of fish processing waste from Alaska and elsewhere. For some of the larger fisheries that harvest over a longer period of time, a great deal of progress has been made with modifications to traditional solutions. For example most of the processing byproducts from pollock (one of the world’s

Case study one

Walleye pollock (*Theragra chacogramma*)
Photo courtesy AFSC

largest human food fisheries) and other white fish are used to make fish meal and oil. This has already made Alaska the second largest producer of fish meal in the United States. But the pollock fishery is huge with roughly 1 million metric tons harvested annually making a more traditional processing approach feasible with relatively small modifications. Additionally, government regulations required processors building new seafood processing plants along the Bering Sea to include machinery designed to effectively handle seafood processing byproducts.

An important and more difficult challenge facing researchers remains to develop reliable methods to stabilize small volume fishery processing waste until it can be dried and worked on after the initial hectic processing season closes. This is important because many Alaskan salmon processors are small, seasonal and remote so they do not have fish meal machinery necessary to handle their byproducts before they spoil.

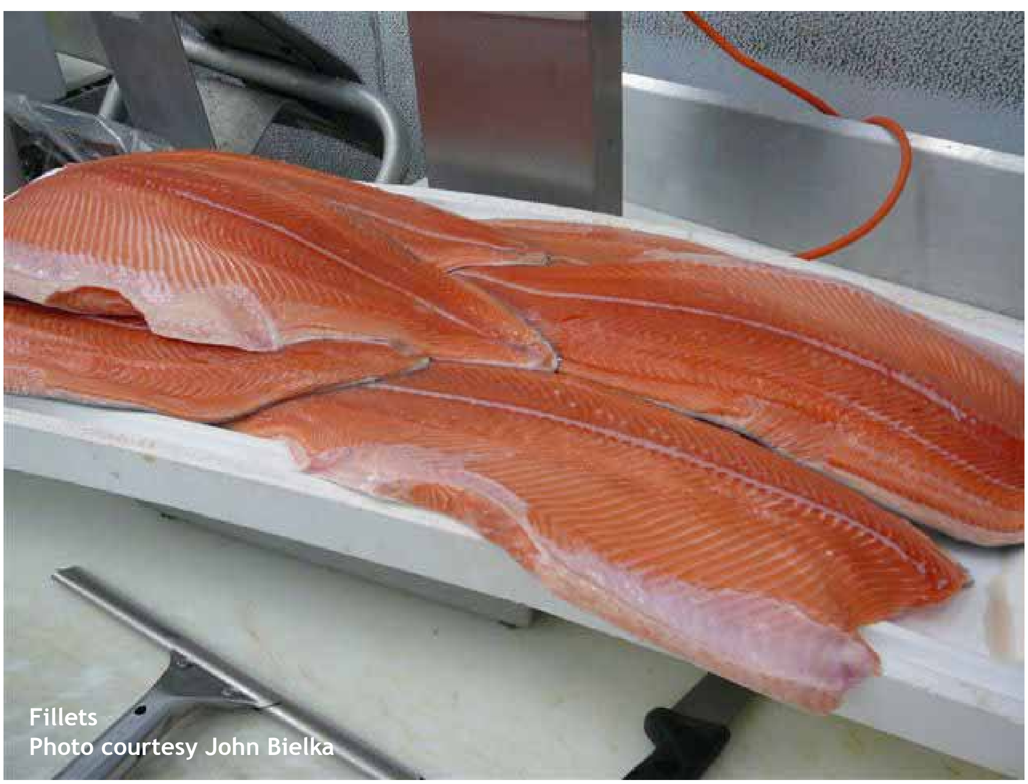
Working collaboratively, researchers have shown that the byproducts of seafood processing can be converted into commercially valuable products including protein meals, oils, and more. In addition, researchers are finding that diets incorporating protein from fish processing waste and used for feeding fish, pigs, poultry, dogs, cats, and even reindeer, are equal in nutritional value to those made with traditional fish meal and oil. Significant progress has also been made by supporting research on the development of new cost-effective processing methods as well as the development of new feed ingredients.

Several collaborative studies demonstrated that seafood byproducts could be stabilized against microbial degradation for the short term (weeks to months) by lowering the pH through the addition of acids—a process similar to how yogurt is stabilized. This stabilization allowed for room temperature storage. Most important, the resulting dried meal remained suitable as a protein feed ingredient for salmon and trout diets. Recently, other stabilization strategies show promise as well, such as using both lactic acid bacterial fermentation and chemical acidification on Alaskan seafood processing byproducts.

Even higher value products can be made from some of the components in the seafood waste stream. Further separation of the components of seafood processing waste can be used to create higher value specialty protein and oil products that may offer a solution to supplementing nutrient deficiencies in plant protein meals and oils being developed for use in aquaculture feed formulations. Studies in collaboration with the processing industries have involved the development of tailored protein powders, and the recovery of usable proteins from a variety of seafood processing waste streams. The human health benefits of fish oils from cold-water species, including the long chain polyunsaturated omega-3 fatty acids, are a good example of a high-value human nutrient that has been developed from this resource.

Continued research in this area promises to reduce the seafood industry's environmental impact and increase the economic viability of both the industry and coastal communities. In fact, this research is now being transferred to the industry. At least one new plant is in the design phase based on the new technologies which will recover 17 million pounds of waste a year that is currently going into the sea. Other companies are increasing the extraction of fish oils from their processing byproducts.

Soon, when you ask a fisherman or a fish farmer about how much of his product is actually used by society, he will be able to reply, "We use everything but the gulp!" It turns out that offal doesn't have to be awful after all.



Fillets
Photo courtesy John Bielka

Case study two

From fish meal-dependent to fish meal-free:
feeds research is producing the alternative diets of the future for trout

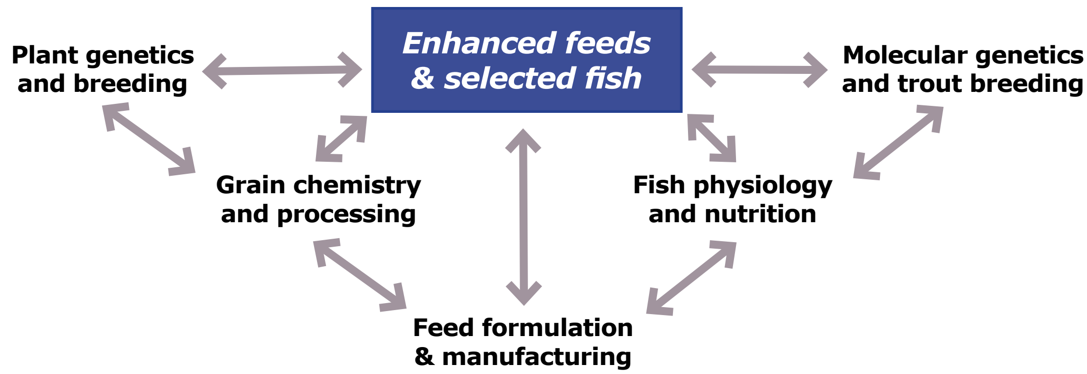
Dr. Fredric Barrows
and Dr. Jeffrey Silverstein
U.S. Department of Agriculture
Agricultural Research Service
Moscow, Idaho and Greenbelt, Maryland

For more than 100 years, rainbow trout have been farmed–or 'cultured'–in the United States. Trout are now farmed in all 50 states and are one of our most valuable domestically grown fisheries products. In 2007, US farmers produced more than 57 million pounds of trout for consumers; state and federal hatcheries release more than 147 million trout annually for restoration, conservation, and recreational purposes.

Feeding these hungry trout presents a challenging research opportunity. For the last 50 years, fish meal has been the primary protein source in trout feeds, with levels up to 50 percent being common. With the rising cost of–and increasing global demand for fish meal and fish oil–fish feed manufacturers are under pressure to find alternative ingredients to replace portions of fish meal and fish oil in aquaculture feeds.

So far, research using alternative feed ingredients demonstrates that fish meal is not a required dietary component for trout. Research also indicates that protein ingredients from sustainable sources can replace most of the fish meal in trout feeds as long as care is taken to ensure that all essential dietary nutrients are present in required amounts and in bioavailable forms. As research studies progress, the trout aquaculture industry will be able to move from fish meal-dependent to fish meal-free feeds.

However, it is not yet an easy or economically feasible task to remove or substantially reduce fish meal and fish oil in aquaculture feeds without affecting the growth and health of the fish. U.S. scientists from the disciplines of grain genetics, grain processing, fish nutrition, and fish genetics have teamed up to approach the



Case study two

problem from different but complementary directions. This multi-disciplinary approach is producing results that have enabled scientists to formulate and test novel trout feeds that are cost-effective and use significantly less fish meal and fish oil than conventional feeds. These studies are helping feed producers move toward the goal of developing fish meal-free feeds.

Alternative trout feeds developed to date are considered prototypes, since they are slightly more expensive than conventional feeds. Further, growth rates of trout remain about 10 percent slower than when a fish meal-based feed is used. However, the new feeds are in the early stages of development and the research is beginning to show that total elimination of fish meal from finfish diets is not only feasible, it also has other performance benefits. For example, research is showing that supplementation of specific nutrients to a plant-based fish diet–including the amino acid, taurine, as well as electrolytes, and higher levels of specific vitamins–results in weight gains equal to trout fed fish meal-based feeds. The resulting fillets are also just as flavorful and nutritious as the fillets from trout fed fish meal-based diets.

Case study three

Plant-based feeds for black seabass show promise

Dr. Wade Watanabe
and
Dr. Md Shah Alam
University of North Carolina-Wilmington
Wilmington, North Carolina

Scientists at the University of North Carolina Wilmington-Center for Marine Science (UNCW-CMS) are developing alternative plant protein based practical diets for the culture of black sea bass, *Centropristis striata*, a commercially important species found in waters along the Atlantic coast from the Gulf of Maine to northern Florida. Their wide acceptance as an excellent food fish and their high market value has led to over-harvesting of wild stocks especially in the South Atlantic U.S. coast. Increased awareness of the status of the black sea bass populations, coupled with high market value and demand, has led to an interest in the development of culture technologies for commercial production. Reliable protocols for spawning and larval rearing of black sea bass are already established. At UNCW, a team of researchers lead by Dr. Wade O. Watanabe, is developing nursery and grow-out technologies for producing marketable fish in recirculating aquaculture systems. Nutrition and diet development are critical components of their research.

Black sea bass grow rapidly when fed prepared feeds consisting largely of marine feedstuffs such as menhaden fish meal or natural foods such as live tilapia. The future potential for limited availability and rising cost of fish meal and live tilapia limit their application in future practical diets.

Case study three

Soybean meal is considered to be one of the most suitable and stable supplies of an alternative ingredient for replacing fish meal in commercial fish feeds. Compared to other grains and oilseeds, soybeans are promising because of their high protein content high digestibility and good amino acid profile. A series of experiments were conducted by UNCW fish nutritionist Dr. Md Shah Alam with the assistance of graduate student Katherine Sullivan to test the effect of varying dietary levels of solvent-extracted soybean meal supplemented with or without amino acids and attractants in the diets of juvenile black sea bass. Diets were formulated to replace menhaden fish meal protein with solvent-extracted soybean meal protein at 0 to 100 percent with or without supplementing amino acids and 1 percent attractants (taurine, betaine, glycine and alanine). All diets were formulated to have about the same crude protein and same oil level for each experiment. To enhance palatability, all diets contained 5 percent krill meal and 7.5 percent squid meal. Results of these experiments showed that the maximum level of menhaden fish meal protein replacement with solvent extracted soybean meal protein was 70 percent with 1 percent attractants, 7.5 percent squid meal and 5 percent krill meal and with or without supplementing methionine and lysine in the diets. Greater than 70 percent replacement of fish meal protein with soybean meal caused growth, whole body protein and oil to decrease. Similar trends were observed for feed efficiency, specific growth rate, feed intake and protein efficiency ratio. These short-term laboratory based studies were extended to pilot-scale grow-out conditions. An experiment to test the replacement of fish meal protein by soybean meal protein without adding squid meal, krill meal and attractants is currently in progress. UNCW scientists are also conducting research to test the flavor and nutritional value of the fish fed the high level of soybean based diets and comparison with the fish fed fish meal-based diets. Results to date indicated that black sea bass exhibited excellent growth when fed feeds containing relatively high levels of soybean meal. These results will be used to develop environmentally-sound and cost-effective plant protein-based feeds for black sea bass aquaculture.


Hatchery raised black sea bass grown to market size in a recirculating tank system at the University of North Carolina Wilmington, Center for Marine Science


Experimental feeds formulated and produced at the University of North Carolina Wilmington, Center for Marine Science

Case study four

Whiteleg shrimp (*Litopenaeus vannamei*)

Shrimp farmers join with researchers to test best new diets

Dr. D. Allen Davis
Auburn University
Auburn, Alabama

The values of shrimp seafood products are declining, stable or in some cases increasing only slightly which is wonderful news for the consumer. At the same time feed, fuel and processing costs are rapidly increasing and causing some U.S. commercial aquaculture operations to cut production costs or go out of business. Given a fixed formulation, the cost of shrimp feeds has almost doubled in the last two years. This is in response to a wide number of factors but was first triggered by rising and unprecedented increase in the price of fish meal from 2006 to 2008. The rapid increase in world fish meal prices was followed by a moderate increase in the cost of other protein sources and a recent rapid rise in grain prices. All of these taken together caused feed costs to nearly double without corresponding increases in the value of the final product.

Although fish nutrition research cannot change world prices, it can provide alternative formulations to moderate feed price increases. Fortunately for the shrimp industry, researchers have been working towards the goal of quantifying nutrient requirements and providing information on the use of alternative feed ingredients for some time. Traditional shrimp feed formulations include 20 to 30% fish meal which is one of the most costly protein sources. Fish meal is an ingredient for which world supply cannot be expanded and is considered a limiting factor for the continued expansion of aquaculture. At this point, experts agree that one of the first steps to reduce shrimp feed prices is to provide alternatives to the use of marine ingredients and develop plant-based diets.

A number of research groups have been systematically identifying nutrient requirements and working to improve feed formulation technologies. Using a variety of funding sources, researchers at Auburn University, Texas A&M, and the Wadell Mariculture Center took the challenge to develop a synergistic program to identify limiting nutrients in plant-based diets and demonstrate their findings to the industry. This included a systematic approach to identifying limiting nutrients in the laboratory, testing diet formulations in outdoor tanks and then in research ponds. Using balanced formulations based on alternative protein sources, primarily of plant origin, resulted in an improvement in the overall nutritional quality of practical diet formulations as well as considerable reductions in formulations costs. These formulations were made possible by systematically identifying limiting nutrients and balancing the formulations as fish meal was removed. For shrimp, identifying the total sulfur amino acid requirement was a key factor to removal of fish meal. Once the fish meal was removed, researchers also discovered essential fatty acids, cholesterol and phosphorus needed to be supplemented to plant-based feeds. Numerous studies have been conducted which have demonstrated the feasibility of reducing or completely replacing fish meal with no adverse effect on the productive performance of *L. vannamei*. These and current trials have demonstrated that practical diets can be formulated using soybean meal as the primary protein source. Other renewable protein sources such as distiller's grain solubles, pea meal and corn gluten meal have been utilized in combination with soybean meal to enhance the amino acid balance and to diversify the ingredient base of these formulations.

Based on these results, the next step was to gain commercial acceptance of reduced fish meal formulations. In order to promote the continued development of quality feed formulations, the American Soybean Association–International Marketing provided funds to transfer feed formulation technologies to the shrimp industry. The project involved working directly with feed mill manufactures and producers in the United States, Latin America (Ecuador, Mexico, Colombia, Venezuela) and more recently Asia to provide technical assistance to both feed mills and shrimp farmers allowing them to improve production practices. With this purpose in mind, a series of regional seminars was conducted in each country to disseminate results obtained at various research centers and to provide sound technical advice on feed manufacturing and culture technologies. Producers and feed manufacturers who were willing to try new practices and improve their operations using plant-based feeds were identified. Shrimp farmers were asked to compare their conventional fish meal-based feed with feed containing less fish meal. The level of fish meal reduction was determined by the producers and feed manufacturer to make them feel comfortable with the experiment. Although controlling experimental conditions in the real world is difficult, farmers were asked to follow a protocol that included using similar sized ponds, using shrimp larvae of the same origin and stocking at similar densities. The production protocols, particularly feed inputs, were reviewed by experts to provide additional technical support to further encourage improved management practices. A similar approach was used with the feed mill manufacturers. Technical support was provided in terms of reviewing manufacturing practices, feed formulation and feed management recommendations. In most cases, improvements in feed manufacturing processes, formulation restrictions and feeding tables were made, resulting in significant reductions in manufacturing costs. Results to date have been encouraging with most farmers and feed mill manufactures adopting the suggested improvements in feed formulations technologies.

Case study five

Seaweed farming may be key for alternative aquaculture feeds

Dr. John Forster
Forster Consulting, LLC.
Port Angeles, Washington

Could seaweeds be used in aquaculture feeds? The answer appears to be yes.

While terrestrial ingredients have served as the immediate replacements for fish meal in aquaculture feeds, the possible use of seaweeds in the future holds the promise that marine aquaculture could, one day, be sustained without using land, fresh water, or fertilizer.

Presently, there are about 14 million metric tons (15.4 million US tons) of seaweed farmed worldwide compared to about one mmt harvested from the wild. Most seaweed is farmed in Asia where about half is used for human consumption and half for industrial processing into marine colloids (used to make paint and foods smooth) and other products. Extrapolation from Chinese production of a seaweed known as *Laminaria*, for which the average yield in 2004 was 19.4 mt dry weight per hectare (8.7 US tons per acre) suggests that the world's present total agricultural output of about five billion mt (5.5 billion US tons) could be matched by seaweed production in an area of 2.6 million km² (1.0 million square miles). This is only 0.74 percent of the 349 million km² (135 million square miles) covered by the world's oceans.

Of course extrapolations can mislead and any development on this scale will take decades, if not centuries. But the potential and its significance are obvious and they prompt a second question: should this be a priority for future research? Again, the answer appears to be yes.

Seaweeds contain valuable amino acids and fatty acids, including omega-3 and omega-6 polyunsaturated fatty acids, marine oils which are part of the reason why seafood is considered healthful–see the fatty acid table. They also contain minerals, vitamins and anti-oxidants as well as being rich in dietary fiber but low in starchy carbohydrates, thereby providing less glycemic load than ingredients derived from grains.

Kelp harvest in China
Photo by Chen Jiaxin

Seaweed	Type of fatty acid (percent of total fatty acid content) Saturated	Monosaturated	PUFA's	Ω6 PUFA's	Ω3 PUFA's	Ω6/Ω3 Ratio
Himanthalia elongate	39.06	22.75	38.16	15.08	18.70	0.81
Laminaria ochraleuca	33.82	19.23	46.94	20.09	25.08	0.83
Undaria pinnatifida	20.39	10.50	69.11	22.10	44.70	0.49
Palmaria sp.	60.48	10.67	28.86	2.14	25.52	0.13
Porphyra sp.	64.95	18.01	16.10	7.97	7.20	1.21

From MacArtain et al., 2007

However, several impediments to utilization in feeds must be overcome before seaweed products can be used, including:

1. Processing (bio-refining) of seaweed to increase the availability of nutrients

In the raw state, seaweed nutrients are protected by indigestible cell walls, or are chemically bound in a way that diminishes their potential nutritional value. Japanese scientists have used fermentation and enzymatic digestion to release and concentrate these nutrients. They have shown that when protoplasts, which contain the bulk of the protein, from the seaweed *Porphyra* are released from the cells after treatment with a polysaccharide degrading enzyme, their inclusion at only 5 percent in feeds for red sea bream led to improved growth and nutrient retention. Significantly, *Porphyra* is known to contain high levels of taurine, an amino acid that has also been found to stimulate growth of fish when they are fed with land plant-based feeds.

2. Species selection and breeding of seaweeds for fast growth and high concentrations of the most valuable nutrients

The science of seaweed breeding lags well behind that of terrestrial plants. However, in China, where most of the world's seaweed is farmed, one variety of *Laminaria* has undergone 15 generations of selection from 1959 to 1974, and grows faster and contains more iodine compared with the natural population. Advances have also been made in protoplast separation and fusion that can produce seaweeds with improved traits through recombination of naturally occurring genes. Northeastern University in Boston is a leader in this field having developed a strain of 'super nori'.

3. Development of large-scale, deep water farming methods to increase the ocean area that can be used for seaweed production

Previous U.S. research from 1968–1990, contemplated large-scale seaweed farming for biomethane production. A new initiative in Japan, similarly contemplates large farms for bio-ethanol production. In both cases, byproducts from energy production might be suitable for aquaculture feeds. But the challenges of large-scale farming for bioenergy are daunting. Per haps, if research focused on the value of seaweeds as feed, it could start on a scale that is more practical and requires less investment.

In the western hemisphere modern aquaculture focuses on the production of aquatic animals. But as seen in terrestrial agriculture, plants support the needs for food, feed and other goods. Is it unreasonable to suppose that, one day, aquatic plants might be able to do the same?

Case study six

Research on diets for threatened and endangered fish species held in captivity gains ground

Dr. Ronald G. Twibell and Dr. Ann L. Gannam
US Fish and Wildlife Service
Longview, Washington

Top photo
Lahontan cutthroat trout
Courtesy of USFWS

Bottom photo
Bull trout
Courtesy of USFWS

For more than a century, the National Fish Hatchery System of the US Fish and Wildlife Service (FWS) has produced economically important species, such as Chinook salmon and rainbow trout, for mitigation purposes. Currently, more than 100 species of plants and animals are reared at the Service's 70 National Fish Hatcheries (NFHs) and seven Fish Technology Centers (FTCs). More than 1.9 million pounds of rainbow trout alone are produced annually by the Service. Considering the amount of fish feed used at NFHs and FTCs each year, the Service is a significant commercial fish feed consumer.

Numerous federally listed species are reared at the agency's hatcheries and technology centers, to support the recovery plans for many aquatic species which recommend propagation of captive fish. The objective of these captive rearing programs generally is to augment remaining natural populations until habitat conditions improve. A few examples of federally protected species currently reared by the Service include bonytail, bull trout, fountain darter, pallid sturgeon, razorback sucker, Lahontan cutthroat trout, and Rio Grande silvery minnow. Among other challenges, hatchery personnel must identify appropriate commercial feed for those and other species reared in captivity.

Aquaculture feeds used in the US have been developed to meet the specific nutritional requirements of a few species, including channel catfish, rainbow trout, salmon and tilapia. The commercial diets available for those species are the result of decades of research conducted by fish nutritionists and feed companies. Even today, fish nutritionists continue to improve diets for commercially important species. But, limited research has been conducted on the basic nutritional needs of any of the federally listed threatened or endangered species of fish reared in captivity.

Case study six

Federally protected species of fish exhibit feeding behaviors ranging from strictly carnivorous to strictly herbivorous. Other than general information on feeding behavior and diet in the wild, relatively little is known about the nutritional needs of these species. Furthermore, some protected species may complete their entire life cycle at a national hatchery and have access only to commercial fish food. As commercial feeds evolve and more alternative ingredients are included in the formulations they will have to meet the nutritional requirements for the entire life cycle of those species and have no detrimental effects on their health or reproduction over long periods of time. Currently, Service personnel are attempting to identify the most appropriate commercial diets for various protected species. For example, studies evaluating commercial diets for Rio Grande silvery minnow, bonytail, and Atlantic sturgeon were published recently. Research on nutritional needs of protected aquatic species is ongoing and is essential for the successful propagation of these animals.

Production of fish feed at Abernathy Fish Technology Center
Photo courtesy USFWS

Case study seven

Soy products and aquaculture are a winning combination

Dr. Michael Cremer
American Soybean Association
St. Louis, Missouri

A market for over six million metric tons of soybean meal has been successfully created over the past 15 years through the development, field testing, and demonstration of all-plant protein, soymeal-based feeds to fish farmers in China. Opening this market to alternative feeds has helped boost China's freshwater aquaculture production from less than five million metric tons to more than 20 million metric tons (5.5 to 22.0 million US tons) by alleviating the necessity for traditional animal protein sources, such as fish meal, in most freshwater fish diets. In the process, it has helped the Chinese aquaculture industry advance from traditional manure-fertilized to modern, feed-based production of the majority of carp, tilapia, catfish and other freshwater fish species farmed in China. This new approach to feed has provided domestic and international consumers with ready access to higher quality farmed seafood from China at reasonable prices, while providing a growing market for US grown soybean products.

Soy products can make up 50 percent or more of the feeds for the carp and tilapia species that comprise nearly two-thirds of the freshwater aquaculture production in China. As an example, a recent pond feeding trial conducted by the American Soybean Association International Marketing program from 2006 through 2008, demonstrated that a 60 percent soy product, all-plant protein feed for grass carp yielded up to 65 percent higher production and up to 500 percent greater profit when compared head to head with a traditional Chinese polyculture system that used a combination of feed and grass. This approach simultaneously reduced the environmental impact of this type of culture by 50 percent or more. A 55 percent soy diet for tilapia not only grows tilapia quickly and with a high feed conversion efficiency, but it provides a healthy 2:1 ratio of omega 6 to omega 3 fatty acids. Other studies have demonstrated that the typical 20 percent fish meal inclusion in fingerling feeds for carp and tilapia can be fully replaced with soy protein concentrate, further alleviating the demand on limited fish meal stocks. The soy-based feeds additionally blend soy and fish oils to reduce dependence on distressed fish oil stocks.

Marine fish and shrimp producers worldwide are also gaining knowledge from research conducted by the US soybean industry. Currently, research is underway to boost soy product inclusion in the diets of key marine fish and shrimp cultured in Asia, Europe, the Middle East, Latin America, and the U.S. A recent study in which soybean meal and soy protein concentrate replaced all but 10 percent of the fish meal in a test diet was successfully demonstrated with pompano farmed in open ocean cages in southern China. Studies in Spain have demonstrated that the protein contribution from fish meal can be reduced to as low as 15 percent in the diet of gilthead sea bream with properly formulated soy feeds, and to 40 percent with European sea bass. A high omega-3 fatty acid soy oil is being tested as a fish oil replacement for yellowtail cultured in open ocean cages in Hawaii. New soy-based diets for white shrimp also have been developed and are being demonstrated throughout Latin America and Asia.

Collectively these studies are reducing the requirement for fish meal and fish oil in aquaculture feeds and helping to improve food safety for consumers, reduce aquaculture's environmental impact, and increase industry sustainability. For additional information on soy use in aquaculture, see www.soyaqua.org.

Pompano *Trachinotus blochii* (photo below) grew from 25g to 610g in 146 days on a diet in which soybean meal and soy protein concentrate were the primary protein sources, and in which fishmeal inclusion was reduced to 10 percent of the diet (ASA-IM feeding trial, Hainan Island, China 2007).

***Pangasius* (photo right) catfish grew from 0.1g to 880g in 181 days on soy-based, all-plant protein feeds with an feed conversion ratio (FCR) of 1.2kg feed to 1.0kg fish gain.**

Photo on opposite page
A three-year pond feeding trial (2006-2008) in China demonstrated that a 60 percent soy product, all-plant protein feed for grass carp yielded up to 65 pecent higher production and up to 500 percent greater profit when compared head-to-head with a traditional Chinese polyculture system that used a combination of feed and grass, while simultaneously reducing the environmental impact by 50 percent or more.